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FINDINGS FROM A LOW-ENERGY, NEW COMMERCIAL-BUILDINGS RESEARCH AND DEMONSTRATION PROJECT

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Abstract—Energy edge (EE) was a research-oriented demonstration project that began in 1985; 28 buildings were constructed to use 30% less electricity than a hypothetical simulated baseline building. Average energy savings for 18 buildings evaluated with post-occupancy tuned simulation models were less at 17%. Only six met the cost of conserved (CCE) energy of 5.6 ¢/kWh for the total package of energy-efficiency measures because the building characteristics changed from design assumptions. Forty-one percent of the individual energy-efficiency measures met the target CCE. The cost effectiveness of the measures would have been greater if the baseline had been common practice rather than the regional building code. The EE small offices use about 30–50% less energy than comparable buildings. Savings also would have been greater if commissioning was included within the program. Future projects should consider lower-cost "hands-on" evaluation techniques with annual check-ups to ensure persistence of savings.

INTRODUCTION

EE, a demonstration project with 28 new commercial buildings, provided conservation planners with information about how energy-efficiency measures perform in actual, occupied commercial buildings. This paper presents a summary of key findings from the multi-year project evaluation.[1] Beginning in 1985, the project, sponsored by the Bonneville Power Administration (BPA), was developed to evaluate the potential for electricity conservation in new commercial buildings. EE involved designing new commercial buildings to reduce electricity consumption by 30% from a hypothetical baseline. Baseline energy was estimated using the 1985 Model Conservation Standards (MCS).[2] The MCS are based on the American Society of Heating, Refrigerating, and Air-Conditioning Engineer's ANSI/IEA Standard 1990-80A, with more stringent lighting requirements.[3]

The primary objectives of the impact evaluation were to assess the overall energy performance of the EE buildings and examine the energy savings and cost-effectiveness of individual energy-efficiency measures. Over 200 individual energy-efficiency measures were tracked. This paper summarizes the energy performance data for all 28 buildings and results from 18 buildings that were evaluated using post-occupancy, calibrated or tuned simulation models.

The need to evaluate the performance of energy-conservation measures is linked to the growth in utility sponsored demand-side management (DSM) programs to deliver energy efficiency. Current U.S. expenditures for DSM exceed $2 billion a year.[4] DSM programs are based on engineering estimates of the predicted performance of energy-efficiency measures (EEMs). Beyond the utilities interests in documenting the energy performance of EEMs is a broader audience for verified performance data that includes among others, buildings designers, owners, and operators. These utility customers need to be confident of an EEM's performance to fully capitalize the stream of expected cost savings as an increase in the market value of their building.

The following section describes the project and the evaluation methodology. We then present results from the tuned models and whole-building energy use trends. The small office buildings are compared to other small regional office buildings to illustrate their relatively low energy use. Next, we discuss the cost-effectiveness of individual classes of measures and total savings for the program as a whole.

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Following that, we describe commissioning, operations and maintenance (O&M) issues. Finally, we describe methodological issues that complicated the evaluation, with suggestions for future programs.

PROJECT DESCRIPTION AND EVALUATION METHODOLOGY

The $15 million EE program began in 1986 with a design competition to identify buildings undergoing initial construction or extensive remodeling. Designs had to use electric heat to be eligible. Computer simulations were developed for each building that entered the competition to evaluate the cost effectiveness of energy saving features. Measures were to be chosen to reduce energy use by 30% from what might have been built without the project's design assistance or incentive payments. BPA paid for the incremental cost of the energy-saving features. The estimated cost effectiveness for the package of measures was to be below 45 mills/kWh saved (4.5 ¢/kWh in 1986 dollars, 5.6 ¢/kWh in 1991 dollars), as further described below. Most building owners also installed additional measures identified in the design studies.

After the buildings were selected detailed monitoring plans were developed and data acquisition systems installed to collect information about how energy was used in each building.[5] Monitoring typically exceeded a full year, with an average of about 100 channels of data, including on-site weather.

The tuned model evaluation methodology was developed to provide a detailed analysis of each efficiency measure based on actual building operating conditions.[6,7] Data collected consisted of utility bills, hourly on-site metering [including major energy end-uses, weather, and limited heating, ventilating, and air-conditioning (HVAC) system performance data], cost data for the efficiency improvements, predicted computer simulation model results, and post-occupancy occupant satisfaction evaluations. Periodic O&M audits were conducted every six months to track building characteristics such as lighting and HVAC equipment inventories, and observe the status of the energy-efficiency measures. BPA adopted a "hands off" approach to observe how each building and energy-efficiency measure performed over time in that the program sponsors did not intervene during the first year of operation to improve the performance of the energy-efficiency measures. We comment below on some of the shortcomings of this approach.

The energy-efficiency measures can be categorized as shell, HVAC, lighting, refrigeration, and miscellaneous other measures. Nearly all of the measures were defined as improvements beyond the building code. The most common measure was increased wall and roof insulation, while window improvements, such as low-emissivity coatings, were common among the buildings. The HVAC measures consisted of various improvements such as adding economizers to small buildings, increasing heat pump efficiencies, and conversion of constant- to variable-air-volume distribution systems. Most of the lighting measures were evaluated as reductions in lighting power densities that involved improved lamps (such as T-8s instead of T-12s), ballasts (solid-state instead of magnetic core-coil) and fixture improvements. Lighting controls, such as occupancy sensors and daylighting were also common lighting measures. Refrigeration measures consisted of efficiency improvements such as head pressure and anti-condensate controls.

After the buildings were occupied (though not always fully), information from O&M audits plus end-use and weather data were used to develop DOE-2.1 simulations to represent the actual building. Model tuning is done by modifying the input assumptions such as outside air flow, infiltration, and schedules until the output meets pre-defined tolerances. The building schedules and weather data were derived from the on-site monitoring. The simulated monthly end-uses were generally within 30% of the monitored end-uses, and within 10% of the whole-building seasonal energy use. Next, site-specific weather data was replaced with statistically valid average weather data (Typical Meteorological Year, TMY) for the site. A baseline model was derived by subtracting all EEMs from the tuned TMY model to describe a fictitious comparable building that meets the MCS code. Each EEM was individually modeled against the tuned baseline, and the levelized cost is calculated. The levelized cost used is equivalent to a cost of conserved energy (CCE at a 3% discount rate) with measure lifetimes based on BPA technical requirements for the Energy Smart Design program. The CCE can be described as

$$\mathrm{CCE} = \frac{\text{initial investment} \times \text{capital recovery rate}}{\text{annual energy saved}} .$$

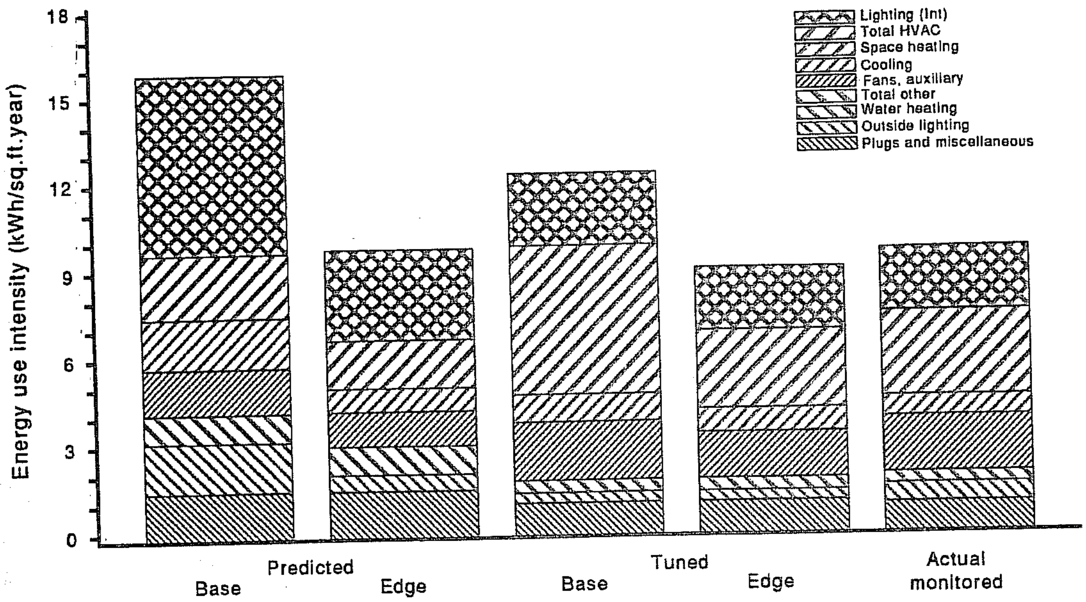

Fig. 1. End-use comparison between design-phase predicted model and tuned model for Siskiyou. MCS code baseline (Base) and Energy Edge (Edge) values are shown. The design-phase predicted, tuned model, and actual monitored total energy consumption differed by only a few percent, but the distribution in energy use among end uses varied greatly. Tuned baseline lighting energy use was less than one-half of the design-phase predicted baseline, while space heating was more than twice design-predicted.

The capital recovery rate (CRR) annualizes the investment. In terms of the real annual discount rate d and measure lifetime n (years), the CRR is given by the expression

$$\mathrm{CRR} = d/[1 - (1 + d)^{-n}].$$

Costs were inflated to 1991 dollars by LBL.

We provide an example of the design-predicted and tuned model energy use and savings for one of the buildings. At the Siskiyou Medical Clinic the tuned model differed from the monitored data in total annual energy consumption by only a few percent. Figures 1 and 2 show the end-use comparisons of

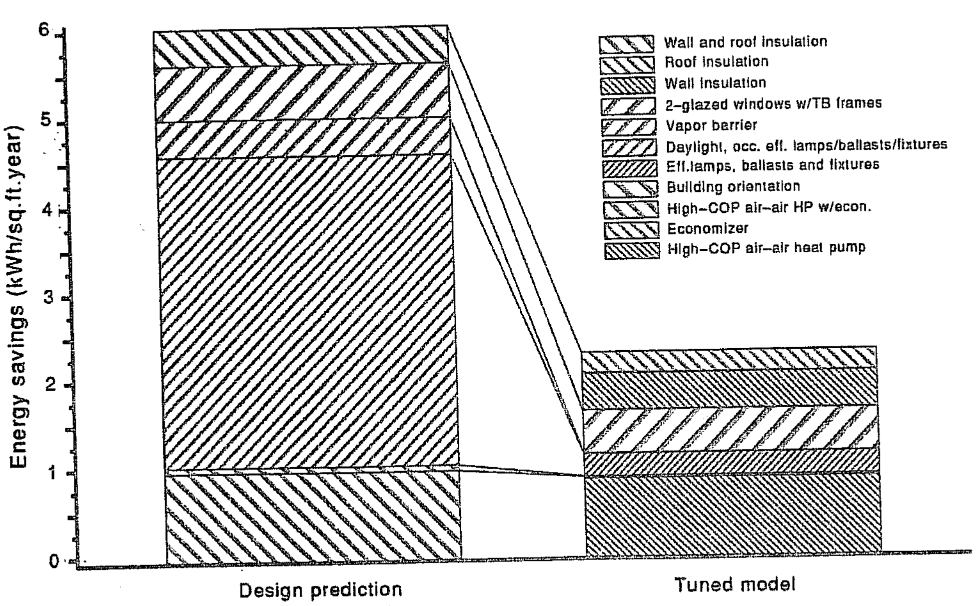

Fig. 2. Savings from individual measures, comparison between design-predicted model and tuned model for Siskiyou. Predicted and modeled savings differ by a factor of three. This difference is due to a variety of reasons, including the non-operation of the economizers and disabled lighting controls.

the design-predicted and tuned consumption and savings by measure for Siskiyou. Early design predictions and actual energy consumption are in close agreement (within 9%), but the predicted and modeled savings differ by a factor of three. This difference is due to a variety of reasons including problems with frozen economizer dampers and poor location of lighting control sensors.

Several factors complicated our ability to compare design-phase and tuned model energy savings estimates. The primary constraint is a lack of information regarding the assumptions in the design predictions. Also, many of the energy-efficiency measures that were installed differed markedly from those considered in the design, and actual building conditions also differ from design assumptions. Another factor was that while the tuned model methodology was designed to be as objective as possible in defining a hypothetical MCS baseline building, defining the baseline is complicated by compliance options within codes, which contain minimal coverage of systems such as controls and their operation.

The challenge in defining an appropriate baseline moves beyond code compliance to ask: What would have been built without EE? and What is common practice? To address these general questions we compared energy-use data from utility bills with regional new buildings stock energy use data to derive a net savings estimate for the program based on a comparison buildings approach. Ideally, this approach would have included developing a statistically valid sample of non-participants to serve as a baseline for the EE buildings. Without such a sample, we drew upon existing buildings data to make the comparisons. We compared energy use and characteristics of both the EE and the hypothetical base buildings with other new commercial construction in the Pacific Northwest using a variety of published data to estimate a typical energy use intensity for each building type. The major drawback of this simple approach of comparing whole-building energy use is that it does not consider conditions in the building that create more intensive loads than typical, such as longer hours of operation, high process loads (e.g., a computer center), or severe climatic conditions.

RESULTS

Energy savings estimated from tuned models

Compared to the total energy use estimated in the design phase, energy use in the actual buildings is, on average, about 40% greater than predicted, as listed in Table 1. Energy use ranges from 32% less than design-phase predicted to 148% greater, with a median increase of 27%. Seven buildings used less energy than predicted.

The greatest increase in energy use is from heating, ventilation, and air-conditioning (HVAC) equipment, which was greater than predicted for 14 of the 18 tuned buildings. More hours of operation and less use of night set-back contribute to the increase. Energy savings from the tuned models were less than design-phase predictions for most of the measures. The lack of savings was not only related to the poor performance of some of the efficiency measures, but was also a result of changes in the actual buildings from the predictions.

Average predicted energy savings for the 18 tuned buildings were 35% of the design-phase baseline energy use. Post-occupancy tuned savings estimates were less, with average savings of 17%. For most buildings, the savings fractions are based on the MCS end use totals only, which do not include plug loads.

Results from the tuned models show that the CCEs for the interactive package of measures funded by BPA range from 1.5 ¢/kWh to one case where there were no net savings. Six, or one-third of the 18 projects with tuned models met the cost-effectiveness criterion of 5.6 ¢/kWh for the total package of measures, and a seventh was within 5% of the target. Only one met the 30% savings target. The most cost-effective measure packages were in the two grocery stores and the fast-food restaurant, involving non-MCS end uses.

Many of the measures in the buildings with the lowest energy-use intensity (EUI) were found to be the least cost-effective. Conversely, many of the measures in the buildings with the highest intensities were the most cost-effective (e.g., McDonald's, Tieton, Thriftway). This result suggests that the evaluation may be biased toward buildings with higher energy use. The building that illustrates this problem most clearly is Eastgate, which used more energy (per unit floor area) than the other offices, yet the measures were found to be the most cost-effective. One reason energy use was high in this building is that they had minimal use of night setback. Therefore, heating measures are more cost effective

Table 1. Energy use, measure savings and cost-effectiveness of the 28 Energy edge buildings.

Building	Location	Floor Area (kft^2)	CCE[a] ($91) (¢/kWh)	% Savings[b] Predicted	Tuned	EUI (kWh/ ft^2year)[c]	% Change in EUI from Prediction
Small Office							
Caddis McFaddin	Spokane, WA	2.1	—	39	—	10	9
Siskiyou	Ashland, OR	3.0	31.0	42	29	8	-7
Hollywood	Portland, OR	3.1	30.7	42	8	11	33
STS	Ellensburg, WA	4.3	67.8	39	15	10	-32
East Idaho	Idaho Falls, ID	5.3	23.6	35	15	13	52
Dubal Beck	Portland, OR	8.5	11.2	28	23	13	32
Landmark	Yakima, WA	13.4	110.4	34	18	14	5
West Yakima	Yakima, WA	16.2	—	33	11	11	48
Large Office							
Emerald PUD	Eugene, OR	24.8	9.9	37	29	10	36
Eastgate	Bellevue, WA	25.1	5.3	40	26	21	148
Director	Portland, OR	79.7	12.0	37	25	12	16
Eugene W&P	Eugene, OR	91.3	—	28	—	20	-22
Bellevue	Bellevue, WA	389.0	na	31	-6	22	5
Montgomery Park	Portland, OR	782.9	—	22	—	16	104
Gateway	Seattle, WA	1,087.0	—	46	—	25	25
Retail							
Evergreen	Tacoma, WA	21.1	2.9	20	5	22	43
Fast Food							
Skipper's	Bellevue, WA	2.5	—	50	—	61	71
Burger King	Vancouver, WA	2.7	2.4	20	7	130	22
McDonald's	North Bend, WA	4.1	3.1	15	19	134	-13
Grocery							
Tieton	Yakima, WA	3.3	3.7	34	16	54	-25
Thriftway	Beaverton, OR	41.6	2.5	36	27	46	5
School							
Marsing	Marsing, ID	31.4	5.8	30	37	10	-3
Edgerton	Kalispell, MT	55.7	53.7	31	10	13	-6
Miscellaneous							
Waves Motel	Cannon Beach, OR	3.3	—	30	—	24	110
O'Ryan	Vancouver, WA	6.0	—	49	—	19	124
Boardwalk	Olympia, WA	12.6	—	38	—	45	142
Rogers Honda	Albany, OR	13.3	—	31	—	24	106
Riverpark	Eugene, OR	47.0	—	33	—	20	13
Average				35	17		40

"—" not available. "na" not applicable (because of negative energy savings). [a] Both CCE estimates are for BPA-funded measures only. (All EPUD measures were owner funded, but considered as BPA-funded because the owner is a utility.) [b] % savings estimates for restaurants and grocery stores and Wave Hotel include all electricity end uses because measures non-MCS code end uses such as cooking; for other building types plug loads are excluded. [c] EUI: Energy-Use Intensity. EUI are from tuned models where available, or the most recent year of bills when not. Some gas is used in Boardwalk, Burger King, Director, Montgomery, Tieton, Riverpark, Skippers, Thriftway, and Tieton.

because of more hours of heating. A simplistic comparison building evaluation approach concludes, on the other hand, that buildings with high EUIs saved less energy than those with low EUIs.

Inconsistencies and gaps in documentation hampered our ability to definitively explain why the design-phase predictions of energy savings differ from tuned model results. There are several reasons for differences. For example, not all of the measures in the design-phase predictions were installed in each building (and in a few cases measures were added). However, the design-phase predicted and tuned CCEs for the set of measures common to both were not necessarily closer. Many measures included in the actual buildings were not included in the tuned model because of partial measure failure, ambiguity, and limitations of the simulation model. For example, since it was difficult to model infiltration changes from vestibules, they were dropped as a tuned measure. Modeling techniques also differed between the design-phase and tuned models. Some measures simply failed because of poor equipment performance (e.g., bad damper linkages in economizers) and installation (e.g., poor day-lighting or occupancy sensor calibration).

The tuned model methodology was developed to account for changes in building conditions that influence energy use, such as equipment loads and schedules. For example, the prediction for the Tieton Convenience Store was based on 24-hour operation and the actual building operated 16 hours per day. We did not, however, anticipate that measure characteristics for both the baseline and the EE systems would change from the design-phase prediction to the actual building. Whereas the design-phase base-line window system used to assess the Low-E windows was a single-paned window at the East Idaho Credit Union, the tuned model baseline was a double-paned window. Therefore, the energy savings from the tuned model were less than from the design-phase model because the tuned baseline uses a

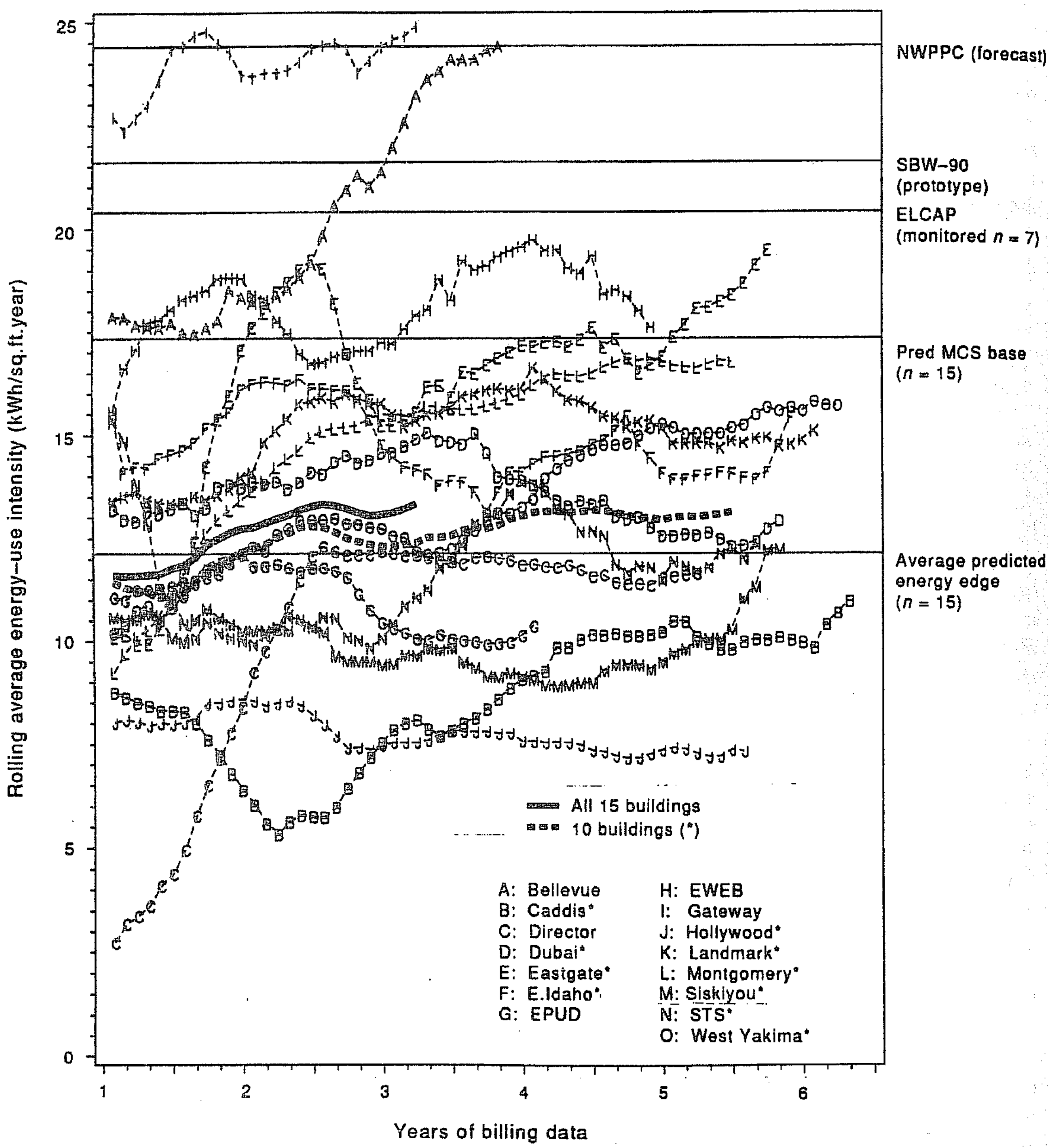

Fig. 3. Energy consumption over time for 15 Energy Edge Office Buildings with comparison buildings. Data are 12-month moving averages from utility bills. Average EUIs for all 15 buildings and the subsample of 10 buildings with five years of data are shown. See text for a description of the ELCAP, NWPPC, and SBW90 comparisons.

more energy-efficient technology. We found differences in both the design-phase and tuned baseline and EE insulation values in most of the buildings.

Building-energy performance trends

From one to six years of monthly utility bills were compiled for all 28 buildings. On average, energy use increased during the first four years of operation, climbing to 36% more than the design-phase predictions. Fourth-year energy use was six percent greater than third year energy use, with no average increase in the fifth year. Compared to the total sample of 28 buildings, energy use for the 15 office buildings were closer to design-predicted consumption. Figure 3 shows how energy use for the 15 office buildings changed over time. The data are 12-month rolling average energy-use intensities (EUIs); each point is the sum of the previous 12-month's energy use, normalized by floor area. Average consumption for the 15 office buildings (continuous thick line) is well below that of the comparison buildings, although EUIs for two of the office buildings (Gateway and Bellevue) have reached or surpassed all three comparisons. The highest of the three comparison EUIs (24 kWh/ft^2 year) is from the Northwest Power Planning Council forecast for new offices.[8] The SBW EUI (22 kWh/ft^2 year) is an estimate of small office building energy use for 1989 common practice.[9] And, the third sample of comparison EUIs based on measured data for seven small office buildings built between 1982 and 1984 (from the End-Use Load Conservation and Assessment Program, ELCAP).[10]

The building characteristics and energy use data for seven small office buildings have been examined in great detail since they are the largest and most homogeneous sample of buildings by type within EE. Figure 4 shows average end use energy for the seven small offices compared to the three regional comparisons also shown in Fig. 3. The design-phase predicted EUI is shown, along with the original baseline. Two average EUIs from the tuned models are also shown, representing the "tuned EE" EUI and the new baseline created from the tuned model (tuned baseline). On average, the EE small office buildings consumed slightly more than design-phase predicted, while the tuned baseline is less than the predicted baseline. Total energy savings per building are therefore less than design-phase predicted. On the other hand, the EE small office buildings use up to 50% less than the comparison buildings. Standard deviations are shown on the figure for the ELCAP and EE results.

We compared the EE building characteristics with results from a study of commercial sector code compliance in the Northwest. The comparison showed that many of the lighting and shell characteristics in the EE offices are as good as, or better, than typical small offices built several years later.[11] For

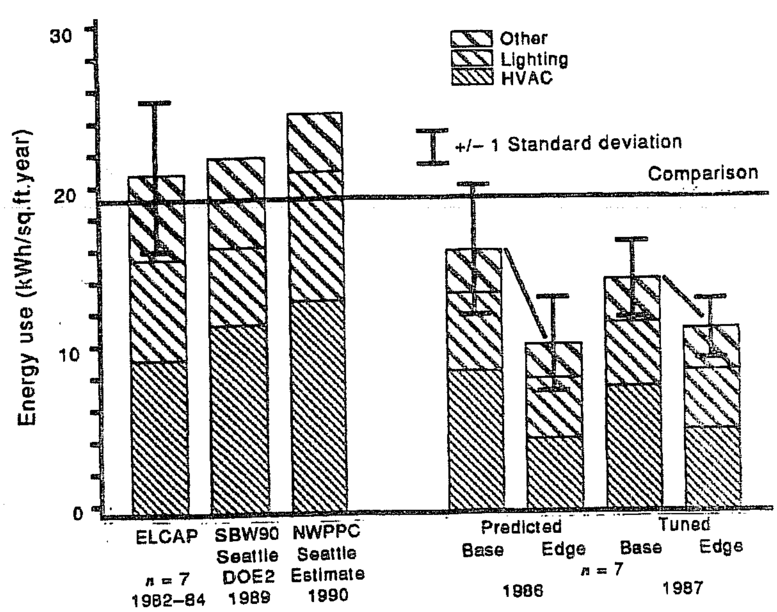

Fig. 4. End-use energy consumption for seven Energy Edge small offices and comparison buildings. Design-phase predicted energy use was lower than actual use (Tuned Edge), and the post-occupancy baseline (Tuned Base) was higher than predicted. However, the post-occupancy baselines are about 30–50% lower than other new comparison buildings data.

example, lighting power densities (LPDs) in the EE small office buildings were lower than typical buildings built in the mid-1980s. The baseline LPD used in EE was the MCS 1.5 W/ft^2. Typical practice in 1986 was about 1.8 W/ft^2. Energy savings from the lighting measures would be greater than the tuned models indicate if the baseline had been common practice rather than MCS compliance. Similar comparisons of shell and other equipment characteristics were explored in the evaluation.

Measure performance

On average, tuned energy savings for individual measures were 20% less than design-phase predicted energy savings. Among the 78 measures evaluated in the 18 tuned building models, 41% met the cost-effectiveness criterion. Predicted CCEs are available for 39 of the 78 measures; only 18 (46%) of these measures met the CCE target. One reason many of the design predictions did not meet the CCE target is that the cost-effectiveness screening was only for the package of measures, not individual measures. So, the most cost-effective measures carried the least cost-effective measures through the screening.

Among the general classes of measures, the refrigeration and measures targeted at miscellaneous end-uses were the most cost-effective with median CCEs of 5.4 and 1.6 ¢/kWh, respectively. Lighting measures were the next most cost-effective at 7.5 ¢/kWh (median), followed by shell measures at 7.8 ¢/kWh. The HVAC measures were the least cost-effective, with median savings of 12.7 ¢/kWh.

The most important reason energy savings were not as great as predicted is that measures changed. For example, the installed insulation levels were often less than the design values, and lighting power densities were higher than initially specified. A second important reason for lower savings was the problems associated with dynamic measures, such as control measures. These measures were often

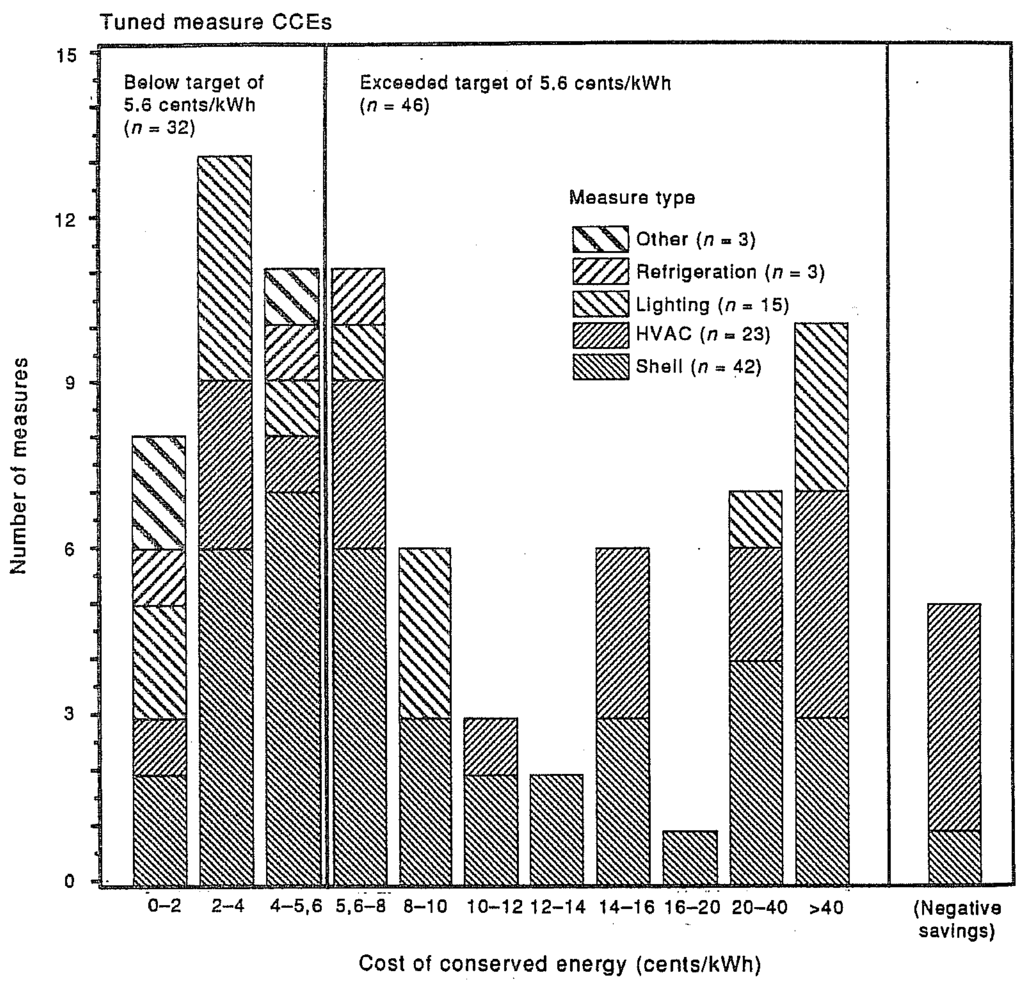

Fig. 5. Distribution of CCEs for 78 measures with tuned energy savings from 18 buildings. Forty-one percent of the measures met the CCE target.

poorly commissioned: that is, they were not correctly calibrated and set-up for proper control and operation. As further discussed below, analysis of specific measures, such as energy-efficient heat pumps and economizers, revealed that ensuring proper operation and control of building equipment can save as much, or more, energy than installing more efficient equipment.

Net program savings

Total energy savings were predicted to be about 17 GWh/year for all 28 buildings. Estimates of the achieved savings range from 13 to 71% of predicted savings, depending on the extrapolation from limited results to total savings for all 28 buildings. The low-end range of savings are dominated by high energy use and low measure savings from the largest buildings. Several of the small buildings consumed less energy than predicted. The highest savings estimate is based on a comparison buildings approach using EUIs.[1] BPA spent about $4.1 million on the incentive payments to the building owners to install the energy-efficiency measures and about $1.6 million to deliver the program, excluding evaluation costs. Based on this, the project was originally estimated to cost about 3 ¢/kWh saved. Estimates of the achieved CCE range from 4 to 22 ¢/kWh based on the range in energy savings.

COMMISSIONING, OPERATIONS, AND MAINTENANCE

Early in the program it became evident that many measures were not operating as intended. Problems ranged from severe disruptions of HVAC systems to minor inconveniences. Examples include control systems not used to set-back HVAC and lighting systems at night, occupancy sensors and daylighting sensors poorly calibrated, dirty filters in ventilation systems that caused low air flow, and frozen or improper operation of ventilation dampers. These problems are not considered unique to the EE buildings; an analysis of typical new buildings would likely identify similar problems, yet buildings rarely undergo such scrutiny.

Commissioning of EEMs is important for utilities to ensure that the efficiency improvements funded through DSM programs achieve optimal energy savings. Several utility DSM programs now include commissioning. One such program developed by participants from EE define commissioning as, "... a set of procedures, responsibilities, and methods involved in advancing a total system from a state of static physical installation to a state of full working order in accordance with the design intent. At the same time, the operating staff are instructed in system operation and maintenance."[12] EE includes a project to develop commissioning procedures that have been tested on one of the buildings, described below.

As the above definition states, operations and maintenance practices need to also be considered to ensure that EEMs achieve optimal energy savings. The energy impacts of poor commissioning, and operations and maintenance practices can be as large as the energy savings from efficiency measures, as illustrated in the following example.

Energy waste from dampers at Siskiyou

Siskiyou has been the subject of a case study comparing the monitored HVAC data to the calibrated simulation model.[13] The calibrated model savings estimated that the heat pump COP improvement from 2.7 to 3.5 resulted in savings of 1180 kWh. The morning warm-up electric resistance heat could have been minimized with a ramp-up thermostat; demand-side management programs that promote efficient HVAC systems should include the appropriate control strategies. The heat pump has an enthalpy economizer that is problematic. While examining the monitored HVAC data we found that during most of the winter hours the dampers were allowing 35% outside air into the supply air. The code requires less than 10% outside based on the low occupancy in the clinic. The open dampers caused a substantially greater increase in heating energy than they saved in cooling energy. We modified the tuned simulation model to allow 10% outside air, resulting in savings in heating energy use of over 6000 kWh.

Energy savings from commissioning at Director building

Following the development of commissioning guidelines a pilot project was initiated to test the proposed approach. A typical commissioning project will include diagnostic procedures during building start-up to ensure that building systems are installed, calibrated, and operated correctly. Certain measures such as HVAC systems may need to be checked during both heating and cooling seasons. The EE pilot commissioning study does not provide a typical example of commissioning because the project began during the building's fourth year of operation. (Energy use climbed dramatically over the first two years as occupants moved into the building, then leveled off as shown in Fig. 3.) The project does, however, illustrate the value of commissioning because several operating problems systems were identified. A few of these problems were remedied and the monitoring provides energy savings data as a result of the changes.

The Director building, a 79,700 ft^2, nine-story office, has a water-loop heat pump system with two to 23 unitary heat pumps per floor. The study revealed that several of the efficiency measures were not working as intended. The commissioning team had a difficult time compiling information on the original design concepts, hampered by the lack of documentation and the inaccessibility of the original design engineer.

The most significant problems at the building were control problems, which included suboptimal use of the Energy Management and Control System (EMCS) time-clock functions and failed daylighting controls. The latter problem was a result of the inadequacy of the stepped dimming, which irritated occupants by frequent clicking and lack of local control. The use of the EMCS was enhanced as a result of the commissioning study and reprogrammed to turn off lights and the unitary heat pumps. The addition of lighting sweep controls for floors three and six through nine that use the EMCS to turn off the lights at night save about 6100 kWh/month, 0.9 kWh/ft^2-year, or 8% of whole-building annual energy use (Fig. 6).

METHODOLOGICAL ISSUES AND RECOMMENDATIONS

The EE evaluation was expensive because of the time required to collect and process the continuous end-use monitoring (which often did not provide suitable information for the analysis of measure performance). In addition, it took about 400 hours to develop each of the 18 tuned models, including the measure savings analysis.[14] As discussed, the results are uncertain for some energy-efficiency measures because of difficulties in defining baseline assumptions. Measures that were most difficult to model are HVAC and lighting controls, and infiltration measures.

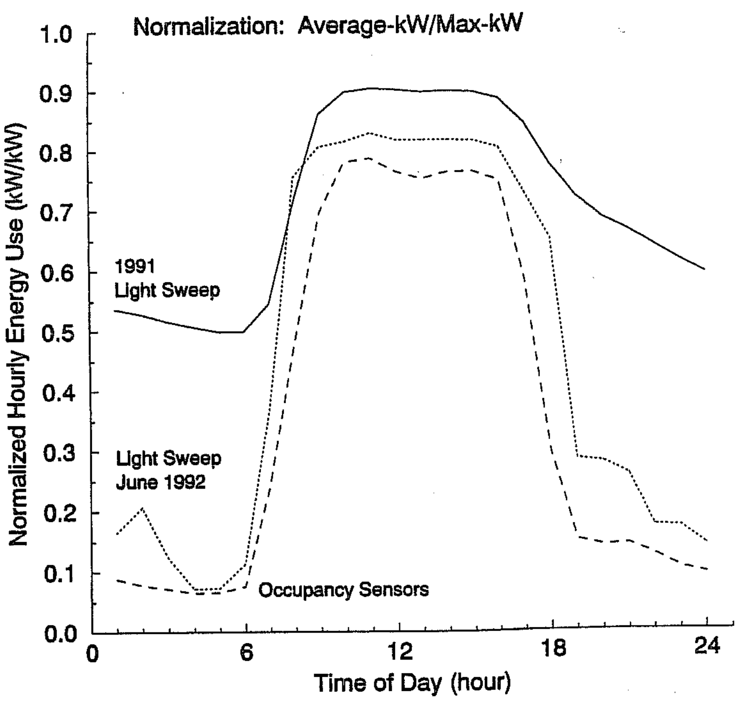

Fig. 6. Lighting load shapes before (1991) and after (June 1992) commissioning of the lighting sweep controls, plus occupancy sensor control. Annual whole-building energy use decreased by 8% following lighting control changes at the Director building. The lowest curve is the 4th floor lighting where occupancy sensor controls are used, causing lower average lighting loads during daytime hours when people leave individual offices.

EE was a "hands-off evaluation. Only on rare occasions were the data used to identify and correct operating problems. More recent monitoring and demonstration programs, such as ACT^2 or the Texas Loanstar Program have shown that "hands-on" evaluations provide valuable knowledge about operating problems and optimal control strategies, increasing the likelihood that actual savings will meet or exceed design targets.[15,16]

As part of the hands-on approach, commissioning is needed to ensure optimal performance of energy-efficiency measures and whole-building systems. These procedures include verifying proper equipment installation and calibration, functional and diagnostic testing, and preparation of O&M guidelines supported by O&M training. Careful tracking of deficiences corrected by commissioning is needed to identify the benefits from this extra step during building or retrofit start-up and urge common practice to make this "business as usual". Annual check-ups revisiting the status of energy-efficiency measures, building conditions, and control sequences should help maintain energy savings over time and provide feedback on persistence of savings.

SUMMARY

Although many of the measures did not perform as well as predicted, there are several successful, low-energy buildings among the 28 case studies. The EE small offices use about 30–50% less energy than comparable new buildings. The lessons from EE, which are far reaching and multifaceted, and the project's success will be based on whether the issues identified in the project have some bearing on what to do (or not do) in related future projects. The EE evaluation was expensive. Future projects will benefit from lower-cost "hands-on" evaluation techniques to verify proper equipment installation and calibration. Annual check-ups revisiting the energy-efficiency measures, building conditions, and control sequences should help maintain energy savings and provide feedback on persistence of savings.

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